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Matera Site Survey and VLBI Invariant Point Determination

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Abstract. The role played by CGS (Centro di Geodesia Spaziale), Matera, Italy as a fundamental geodetic station, hosting the main space geodetic technique systems SLR, VLBI, and GPS, makes the whole survey theme (measurements, related corrections and processing) of great importance for the CGS activities. The last geodetic survey at CGS was performed in Feb.–Mar. 2004 and involved measurements connecting 7 IERS geodetic reference points and 14 additional reference points in the local network. During July 2005, a measurement campaign was carried out to estimate the VLBI invariant point (IVP) from the geometrical surface described by four optical retro-reflectors mounted on the antenna structure.

1. Introduction

The purpose of this work is the determination of the tie vectors between the IERS geodetic reference points located at the CGS. To achieve the results, three steps have been performed. The first one was the determination of the local network that provided the ties between the GPS and the SLR instruments. The second one was the establishment of a small network around the VLBI antenna with several points in common with the previous network. Then the determination of the VLBI antenna invariant point (IVP) has been obtained recovering the geometrical figure described by four retro-reflectors on the antenna dish.

2. Analysis Software

An original software (GSMAT) for the analysis of a geodetic survey raw measurements has been developed at CGS. The main characteristics of this software are:

- atmospheric effects removed using continuously measured values of local temperature, pressure and humidity recorded by the local meteorological sensors;
- rigorous network adjustment (weighted least squares method) with minimal inner constraints (via SVD), using the whole covariance matrix at each step of the computation;
- outlier detection/rejection;
- the VLBI invariant point estimation by modeling the geometrical figure described by retro-reflectors located on the antenna;
- production of the SINEX file reporting the coordinates of the IERS reference points and VLBI IVP.

3. Matera Local Survey

3.1. Local Survey Description

The Matera local network is formed by 20 points, 6 of them being IERS reference points. The measurement instruments used were: a theodolite Tachymat Wild TC2002S, a laser distance meter Distomat Wild DI2002 and a corner cube reflector Wild GPH1P. Up to 967 measurements where carried out, each one composed by horizontal and vertical angles and slant distance between the theodolite and the corner cube mounted over the markers.

3.2. Local Survey Data Analysis

The procedure for the computation and analysis is the following.

1. Correction of distances for atmospheric refraction using the "Barrel and Sears" formula and meteo data.
2. Correction for the height differences between the instruments (tachometer and reflectors) and the markers.
3. For each setup of the theodolite, transformation of vectors from the topocentric polar reference system (azimuth, elevation, distance) in a topocentric rectangular reference system centered in the marker occupied by the theodolite with unknown orientation angle w.r.t. the astronomical azimuth.
4. Minimal inner constraints solution via Singular Value Decomposition to solve for unknown orientation angles and marker coordinates in an unique arbitrary topocentric rectangular reference system.
5. Use of the Polaris star to orientate the network w.r.t. the astronomical North direction.
6. Translation of the network to the ITRF2000 position of the GPS marker.

4. VLBI Invariant Point Determination

In order to determine the VLBI antenna IVP with respect to the local network, we placed 4 retro-reflectors on the antenna dish and measured their position while the antenna moved. This operation realizes a small network formed by several points belonging the the local network plus the IVP point. Adjusting this sub-network to fit the local network, the ties between the IVP and the other reference points has been obtained. The procedure can be summarized as follows:

- Analysis of the sub network around the antenna using the same procedure for the local network (see 3.2).
- Roto-translation of the sub-network to fit the whole local network.
- Estimation of the VLBI invariant point coordinates modeling the surface described by the corner cubes on the antenna as a tilted "spindle torus".
- Production of the SINEX with coordinates of the space geodetic instruments in the ITRF2000 reference frame.

4.1. IVP Mathematical Model

When the antenna moves, a point belonging to the dish structure describes a torus in the space. For the VLBI antenna at the CGS, in theory, such torus degenerates in a sphere since the azimuth and elevation axes do intersect each other at the IVP. However, in order to take into account possible construction errors, we treated it as a "spindle torus", with the internal radius shorter than the external one.

The weighted least square method implemented minimizes the following torus equation and determines the invariant point position (x_0, y_0, z_0), the radius of each torus being described by the corner cubes and the internal torus radius. The internal radius is the same for all corner cubes and it represents also the distance between the two rotational axes, that is the antenna axis offset.

$$f_i = \sqrt{\left(R \pm \sqrt{(y_i - y_0)^2 + (z_i - z_0)^2}\right)^2 + (x_i - x_0)^2} - R_k = 0\,. \qquad (1)$$

Where:
R = internal torus radius,
(x_0, y_0, z_0) = position of the invariant point of the antenna,
R_k = external radius of the torus described by the corner cube k,
(x_i, y_i, z_i) = position of the corner cube at observation i.

The $\pm$ sign is positive for the internal surface (called "lemon") and negative for the external one (called "apple"); our case is the "apple" type.

In order to take into account a possible non-verticality of azimuthal axis and non-perpendicularity between the two axes, we also introduced a tilt for the torus and estimated two angles of rotation around the East and North directions

$$R = R_z(u)R_y(e) = \begin{pmatrix} \cos(u) & \sin(u) & 0 \\ -\sin(u) & \cos(u) & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos(e) & 0 & -\sin(e) \\ 0 & 1 & 0 \\ \sin(e) & 0 & \cos(e) \end{pmatrix} . \quad (2)$$

Then the minimized function will be:

$$f_i = \sqrt{\left(R \pm \sqrt{y'^2 + z'^2}\right)^2 + x'^2} - R_k = 0 \, . \quad (3)$$

Where:

$$\begin{cases} x' &= \cos(e)\cos(u)(x - x_0) - \cos(e)\sin(u)(y - y_0) + \sin(e)(z - z_0) \\ y' &= \sin(u)(x - x_0) + \cos(u)(y - y_0) \\ z' &= -\sin(e)\cos(u)(x - x_0) + \sin(e)\sin(u)(y - y_0) + cos(e)(z - z_0) \, . \end{cases}$$

5. Results

The results of this work are the estimates of ties between the IERS reference points and the VLBI antenna axis offset. A comparison of our results for the local ties is given in Tabl. 1 in terms of cartesian coordinate differences. The differences for the GPS marker R are zero because the local network has been translated to its ITRF2000 position.

Table 1. Comparison of the local ties w.r.t. ITRF2000

Local marker name	CDP code	IERS dome number	DX, mm	DY, mm	DZ, mm	description
R	MATE	12734M008	0.000	0.000	0.000	GPS MATE
IVP	7243	12734S005	−2.634	−0.005	−2.918	VLBI IVP
M	7941	12734S008	0.072	3.991	−1.203	SLR MLRO
N	MAT1	12734M009	−10.403	0.529	13.103	GPS MAT1
B	7540	12734M005	−3.774	−0.666	6.914	SLR pad
C	7541	12734M004	−4.940	−2.366	8.776	SLR pad

Concerning the determination of the antenna axis offset, we estimated a value of −8.329 mm ±0.303 mm. A comparison of this value w.r.t. VLBI analysis results from different analysis center and different analysis software is given in Tabl. 2.

Table 2. Comparison of the antenna axis offset result with VLBI analysis results

VLBI solution	Axis offset value, mm	Agency	Software
gsf2007d	-3.4 ± 0.4	NASA/GSFC	CALC/SOLVE
iaa2007c	-5 ± 0.6	IAA	QUASAR
	-0.24 ± 0.16	MAO	SteelBreeze
usno2007a	-4.51 ± 0.44	USNO	CALC/SOLVE
gsi2007d	-4.07 ± 0.39	GSI	CALC/SOLVE
cgs2007a	-3.54 ± 0.66	CGS	CALC/SOLVE

6. Possible Improvements of the Results

Improvements of the results should be possible under the following refinements of the measurement and computation procedure.

- Using levelling measurements to decrease the errors on the vertical position of the markers.
- Increasing the coverage of the surface described by the antenna.
- Taking into account gravitational and thermal antenna deformations.

7. Conclusions

- A dedicated software (GSMAT) has been developed at CGS. It performs rigorous network adjustment, determines the antenna invariant point and antenna axis offset.
- The network adjustment has been obtained solving the weighted least squares problem with the minimal inner constraints to avoid network distortion and using the singular value decomposition.
- The whole variance-covariance matrix has been used at each step of the computation.
- The antenna invariant point and its axis offset have been successfully determinated using classical survey measurements and the mathematical model described in this work.
- The new geodetic survey results have been provided to IERS to be used in the inter-technique combination for the ITRF determination.

References

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